

Wind Tunnel Studies on the Shelter Effect of Porous Fences on Coal Piles Models of the CVRD – Vitória, Brazil

Paper # 1161

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ABSTRACT

The effects of using wind fences to reduce wind-blown coal dust were studied through wind tunnel tests. The mean and fluctuating pressure distributions over the surface of reduced coal pile models were measured. The tests were performed at a 1/300 scaled model of a typical coal pile of the *Companhia Vale do Rio Doce* (CVRD) open storage yard, at Vitória, Brazil. Different fence porosities (68%, 53%, 37%, 0%) as well as different fence positions and heights were tested. Further to the pressure measurements, the field velocities over the surface and surroundings of the piles were obtained through hot-wire anemometry measurements. The fence with no porosity (0%) caused an increase in the re-circulating zone behind the fence, therefore increasing the negative pressures over the pile surface, being soon disregarded. The fences with porosities ranging from 53% to 68% were most effective in reducing the pressure fluctuations on the windward face of the pile, without increasing significantly the mean pressures over it. These pressures are closely related to the dust emissions from the surface, directly affecting the surrounding environment. Although most effective for reducing pressure fluctuations, the best combined effect together with the drag surface velocities were found for the fences with intermediate porosities.

INTRODUCTION

The Companhia Vale do Rio Doce (CVRD) needs to solve a problem of dust emission from coal piles at the yards located at Tubarão Harbour, in the city of Vitória, ES, Brazil. These emissions result in the loss of the product (coal), and eventually in an environmental hazard if the particles reach urban areas¹. The phenomenon is illustrated in figure 1

Among the several actions implemented by CVRD for the control of the coal emissions, stands out the water aspersion procedure. For improvement of the existing control, the CVRD decided to study the effectiveness of the use of porous screens (*wind fences*) for reduction of the speed of the incident wind on the stacks and consequent reduction of the drag of the coal particles to the atmosphere.

Figure 1 – Coal particle Aeolian transportation.



Figure 2 – View of the CVRD coal yard.



The study had the aim of quantifying, through reduced models in wind tunnel, the protection effects propitiated by porous screens to coal particle aeolian transport. Similar studies are described by Lee *et al*^{2,3}. Representative coal piles were modeled, corresponding to a typical disposition in the yard of the Companhia Vale do Rio Doce (CVRD) - Industrial Complex of Tubarão (see figure 2), for different configurations of screens e wind incidences.

The study was divided in two phases. Firstly, the modeling of an isolated pile in wind tunnel was performed, and secondly, the wind tunnel modeling of a representative set of piles, typical of the CVRD coal yard in Tubarão. This paper relates to the first phase, and describes the flow characteristics around an isolated coal pile with the intention to subsidize characterization of the local carrying phenomenon and beginning of erosion, as well as to understand the influence that protection screens exert on this phenomenon. A detailed description of the site and its neighborhood is found in Loredou-Souza *et al*⁴. The tests were carried out in the Laboratory of Aerodynamics of Constructions of the Federal University of the Rio Grande do Sul, Brazil^{5,6}.

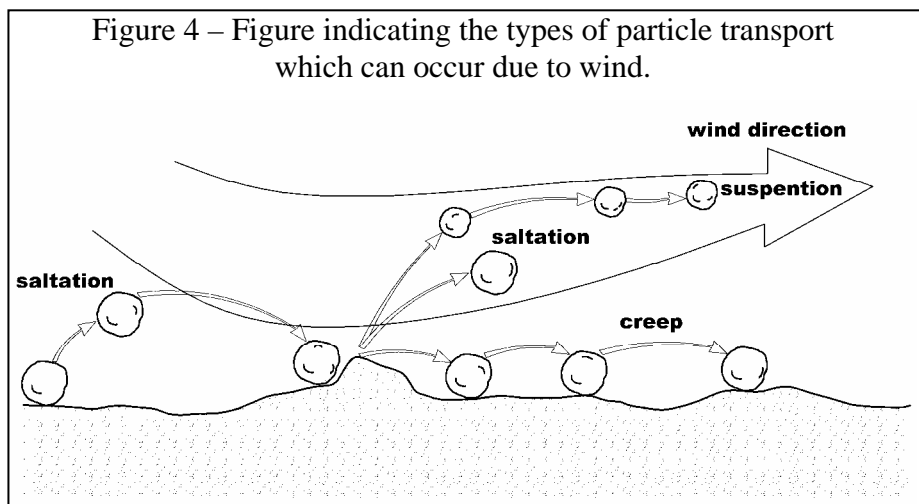
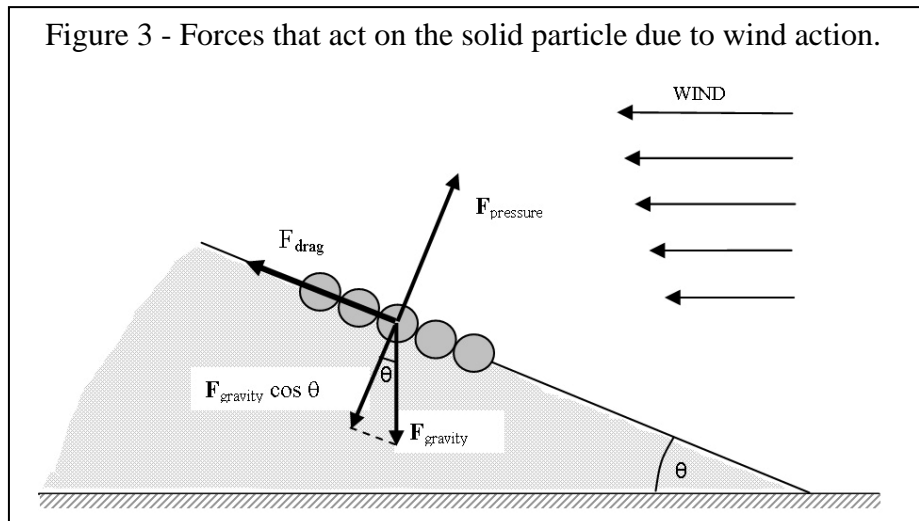
STATEMENT OF THE PROBLEM

Fine particle erosion in stacks of material stored in open yards is a consequence of the acting wind in the region next to the surface of the piles. The forces acting on the particles are those of gravity, pressure and viscosity. The gravity force depends on the diameter of the material and its specific mass; the forces of pressure and viscosity depend on the flow field generated around the pile. The resultant of these three forces, if decomposed in the direction of the flow and in the perpendicular direction to it, results in the called aerodynamic forces: lift force (F_L) and drag force (F_D) (Figure 3).

The aerodynamic forces are responsible for the movement of the grain. Three types of movement can occur (Fig. 4):

- Rolling: movement due to drag of the grain by rolling, dependent of the wind velocity field next to the surface of the pile;
- Saltation: lift of the grain due to the pressure field generated by the flow, with the grain returning to the surface;

- Suspension: lift of the grain due to the pressure field generated by the flow and consequent carrying of the grain to the atmosphere.



Besides the transportation mechanisms, it is important to understand the flow characteristics around the pile. A qualitative two-dimensional description of the airflow in a vertical plane over a sharp-edged bluff body shape can be described by three regions. A first region far from the body with relatively lower intensity of turbulence (external flow); a second region with higher intensities of turbulence than the first region, the turbulent wake, located immediately over the body; and a third region, the vortex layer, which is a layer of vortices shed from the point of separation on the body, located between the other two regions.

WIND TUNNEL TESTS

For the study of the flow characteristics around the coal piles, a reduced model was built in a 1/125 scale. The model was instrumented with 62 pressure taps for measurement of the mean and fluctuating pressures in its surface. A Picture of the model is shown in figure 5. The tests were performed at the *Prof. Joaquim Blessmann* Boundary Layer Wind Tunnel of the *Universidade Federal do Rio Grande do Sul* (Fig. 6). The simulated wind corresponds to categories III and IV according to the Brazilian Wind Code⁷.

The study it was carried out for 41 configurations, which are indicated in Figure 7. The configurations represent distinct combinations of porosity, height and position of the screens in relation to the pile. The configurations are represented by codes, which are explained as follows:

- *Location of the screen*: "**AB**" represents the screen in the parallel position to the biggest geometric axis of the pile, "**CD**" represents the screen in the perpendicular position to the biggest geometric axis of the pile;
- *Porosity of the screen*: "**K**" represents 68% porosity, "**L**" represents 53% porosity, "**M**" represents porosity of 37% (however with bigger spacing of the screen wires), "**N**" represents porosity of 37% (however with a minor spacing of the screen wires), "**O**" represents 0% porosity (solid plate);
- *Height of the screen*: "**R**" represents height of the screen equal to the height of the coal pile ($1.0H$, with H being the height of the pile), "**S**" represents height of the screen equal to one and a half times the height of the coal pile ($1.5H$, with H being the height of the pile);
- *Distance of the screen*: "**X**" represents the distance between screen and pile equal to the half of the height of the pile ($0.5H$, with H being the height of the pile), "**Y**" represents the distance between screen and pile equal to one and a half times the height of the pile ($1.5H$, with H being the height of the pile).

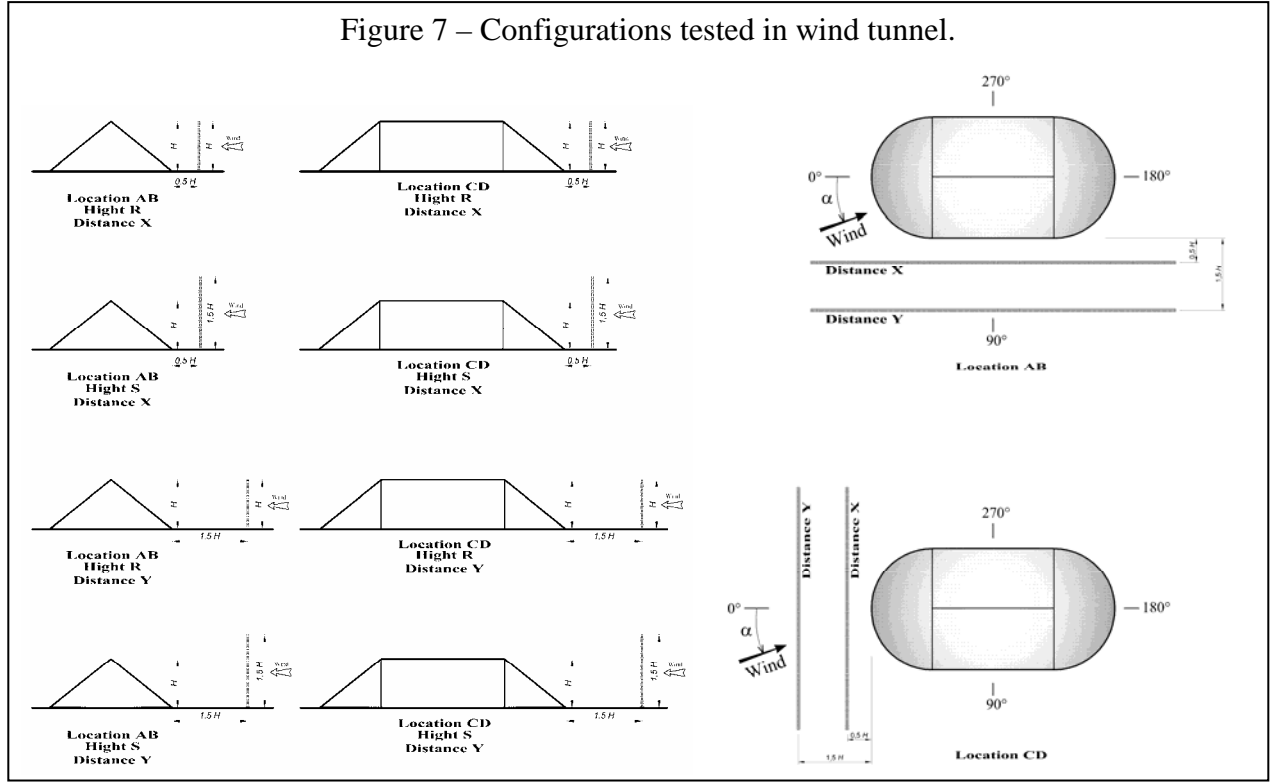
Figure 5 - View of 1/125 model in wind tunnel.



Figure 6 - View of boundary layer wind tunnel.



Figure 7 – Configurations tested in wind tunnel.



Equation 1. Mean wind velocity profile expressed, approximately, for the potential law:

$$\bar{V}(x_3)/\bar{V}_{ref} = (x_3 / x_{ref})^p ,$$

where $\bar{V}(x_3)$ is the mean wind speed at a height x_3 , \bar{V}_{ref} is the mean wind speed at a reference height (in the tunnel, $x_{ref} = 450mm$ – height of the longitudinal axis of the tunnel), and $p = 0,23$.

Velocity Measurements

The wind speeds at selected points over the models were measured with a hot-wire sensor⁸. Measurements of the mean wind speed and turbulence intensity were made at several positions around the coal pile models. The reference velocity for the normalized intensity of turbulence and normalized mean velocity is the mean wind speed at the top of the pile (16 m, full-scale).

Measurements of the instantaneous wind velocities ($U(z)$) were performed in several vertical positions around the coal pile model. From these measurements, the mean and fluctuating (*rms* - root mean square) wind velocity were calculated, being represented respectively by $\bar{U}(z)$ and $u'(z)$. Those were normalized with the mean wind speed at the top of the pile:

Equation 2. Normalized wind speed and intensity of turbulence.

$$\bar{U}_{ad}(z) = \bar{U}(z)/U_{ref} , \quad \text{and} \quad I(z) = u'(z)/U_{ref} ,$$

where:

u' - *rms* value of the wind velocity fluctuations, in the main flow direction, at a height z ;

U_{ref} - reference mean wind speed, in the main flow direction, at the top of the pile (16 m).

Pressure Measurements

The model was instrumented with 62 pressure taps (figure 8) and the pressures measured with electronic pressure transducers⁸. From the recorded time series, the mean and *rms* pressure coefficients at the model surface were obtained.

Equation 3. Mean and rms pressure coefficients.

$$\bar{c}_p = \frac{\frac{1}{T} \int_0^T p(t) dt}{q} \quad \tilde{c}_p = \frac{\sqrt{\frac{1}{T} \int_0^T (p(t) - \bar{p})^2 dt}}{q},$$

where:

$p(t)$ = instantaneous pressure, at the pile surface;

\bar{p} = mean value of $p(t)$ for the sample time T ;

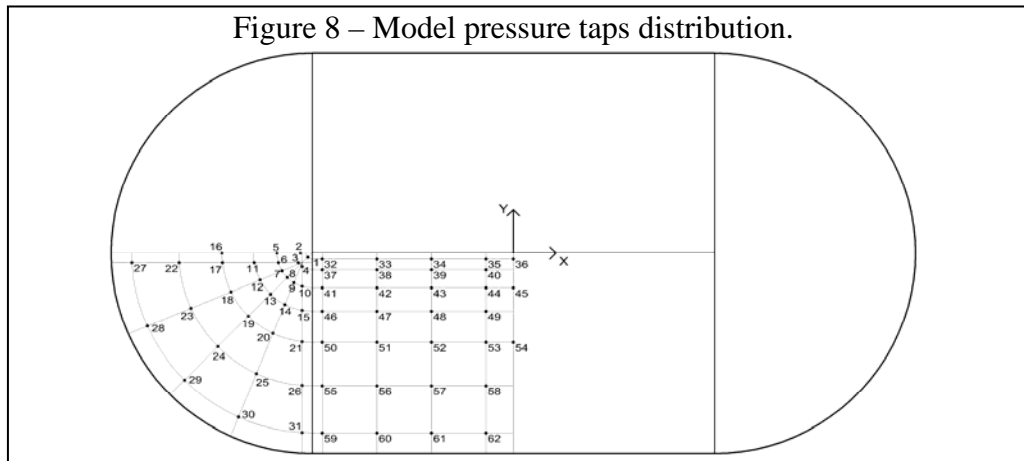
t = time;

T = sample time;

$q = \frac{1}{2} \rho U^2$ = pressão dinâmica de referência;

ρ = air density;

U = reference mean wind speed, at the top of the pile (16 m), real scale.



RESULTS AND DISCUSSION

Velocity Measurements

Vertical mean wind velocity profiles were obtained around the pile model, which are shown in figures 9 to 14. They represent the mean and *rms* wind velocities for three porosity configurations, namely 100% (no fence), 68% and 37%.

In the case of the mean speeds, two differentiated slightly points appear in the windward region of the pile. For the cases "without fence" and with the most porous screen (68%, screen K), the average wind velocities next to the pile are higher than the equivalent average velocities for the cases with lower porosities (37% and 53%), showing that the reduction of the porosity implies in a reduction of the wind speed. Regarding to the intensity of turbulence, the presence of a less porous screen produces a reduction of these values, also implying in a beneficial effect if compared with the others two cases. The presence of screens and its porosity modifies the thickness of the vortices layer: the lesser the fence porosity is, the lesser the layer thickness becomes. These observations do not imply in a reduction of particle erosion, since it depends on other factors as the pressure field.

With purpose to illustrate the results obtained, negative average velocities in the profiles have been plotted in the recirculation region, leeward of the pile.

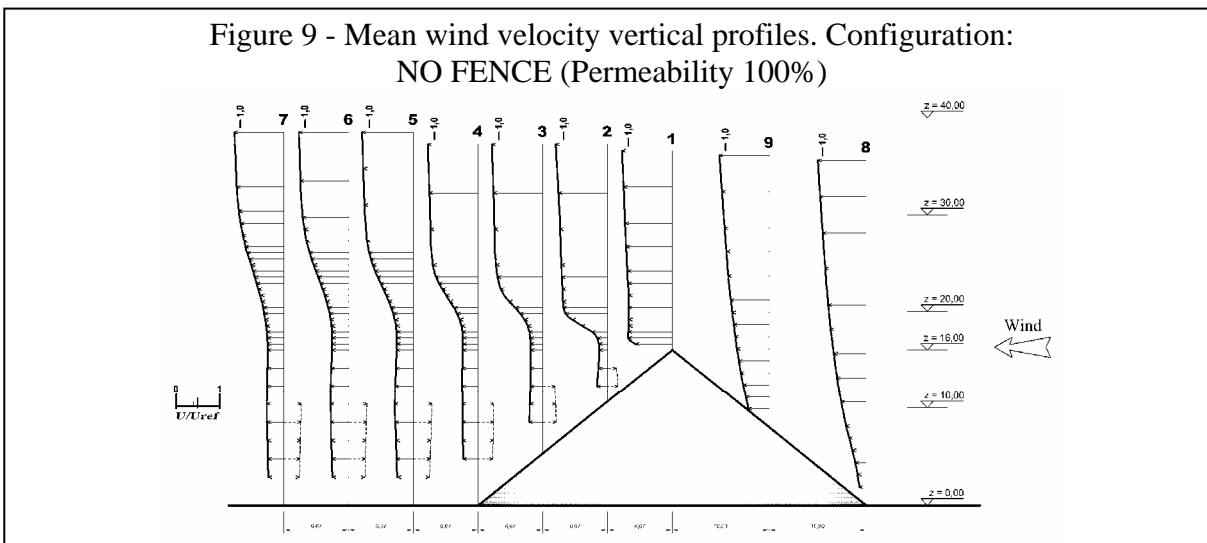


Figure 10 - Normalized intensity of turbulence vertical profiles. Configuration:
NO FENCE (Permeability 100%)

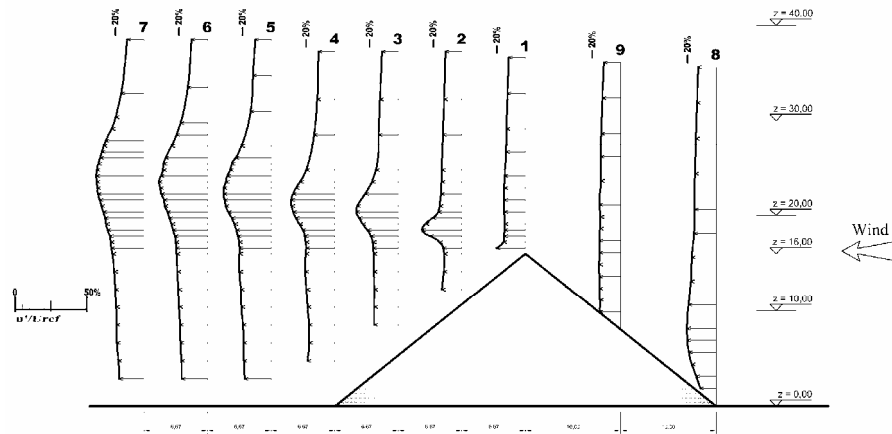


Figure 11 - Mean wind velocity vertical profiles. Configuration:
FENCE AB-KRY (Permeability 68%)

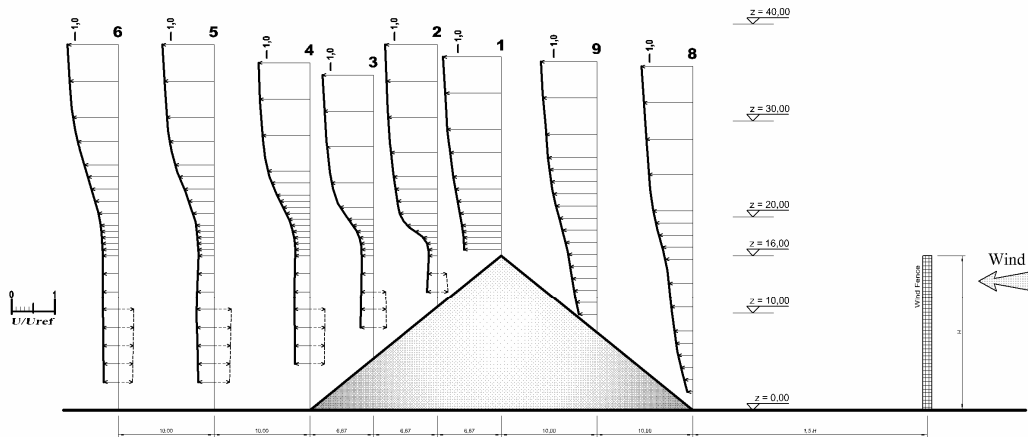


Figure 12 - Normalized intensity of turbulence vertical profiles. Configuration:
FENCE AB-KRY (Permeability 68%)

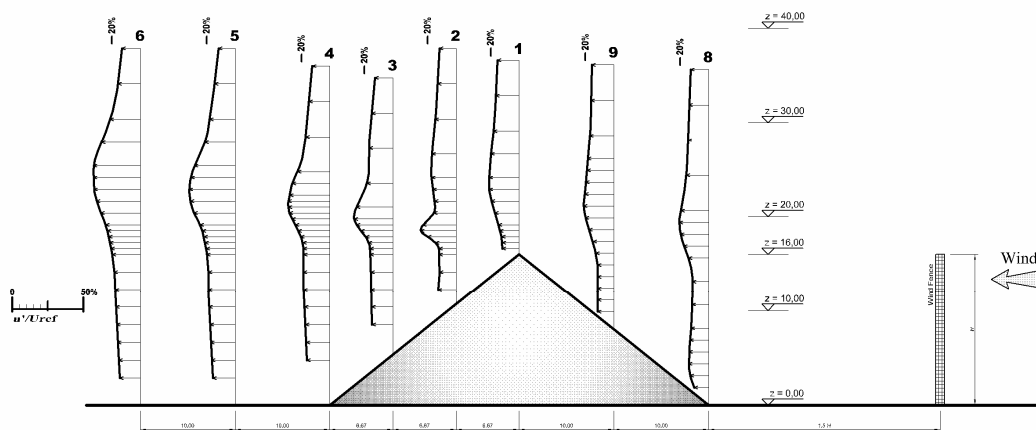


Figure 13 - Mean wind velocity vertical profiles. Configuration: FENCE AB-MRY (Permeability 37%)

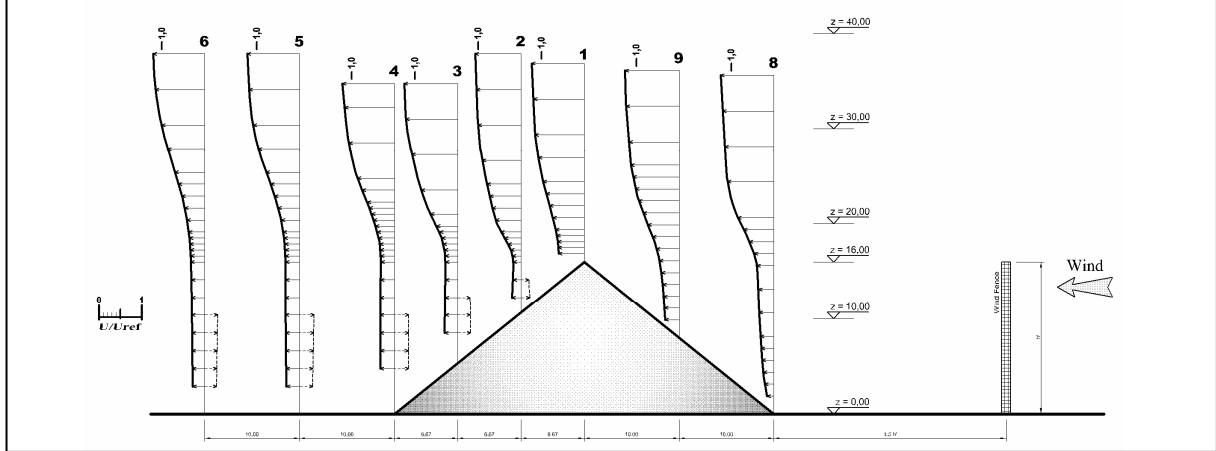
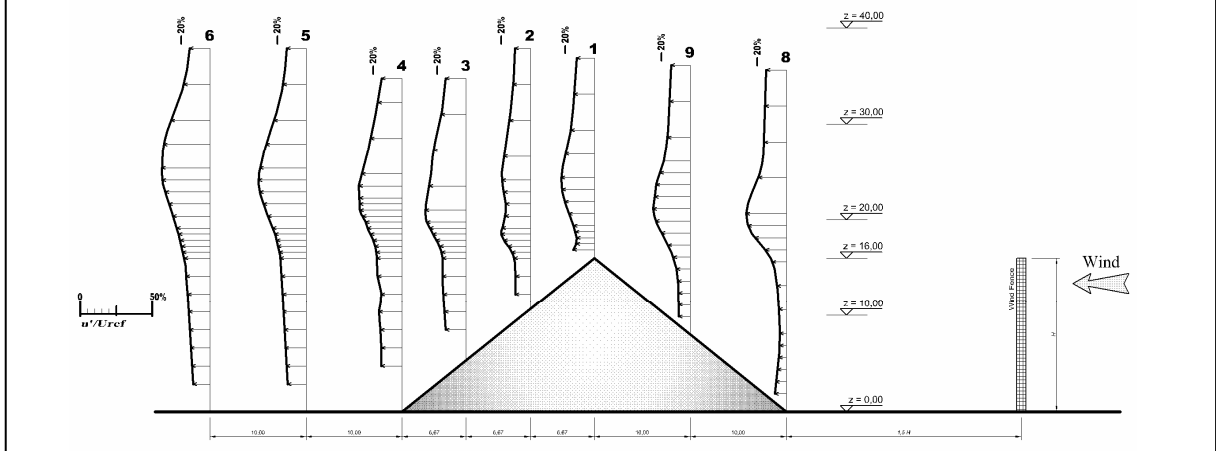


Figure 14 - Normalized intensity of turbulence vertical profiles. Configuration: FENCE AB-MRY (Permeability 37%)



Pressure Measurements

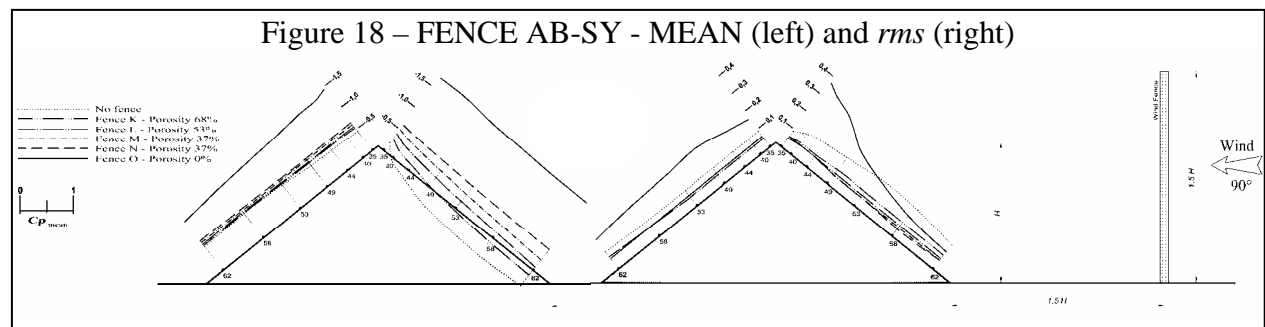
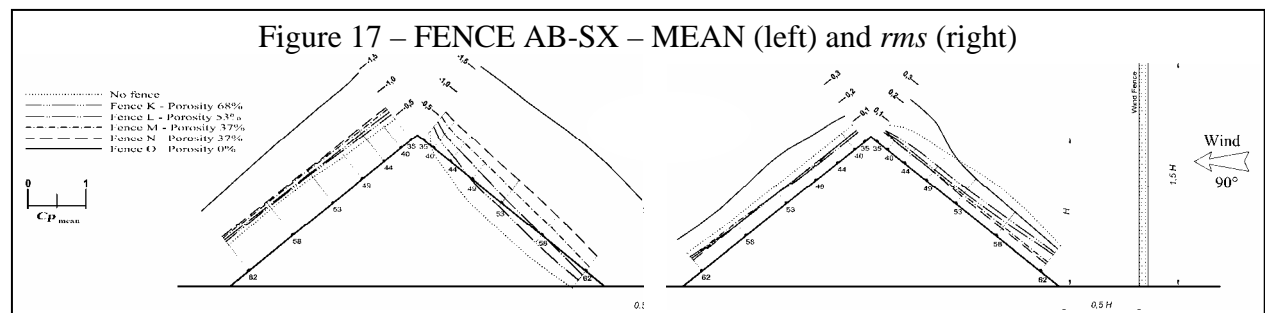
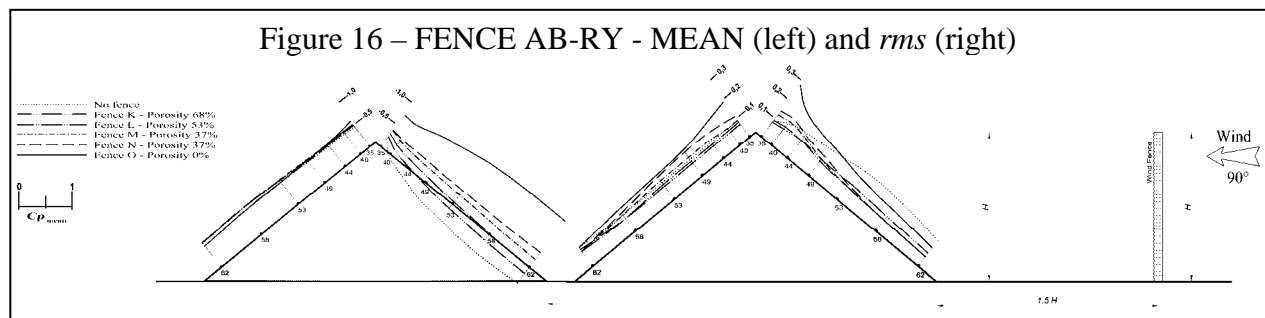
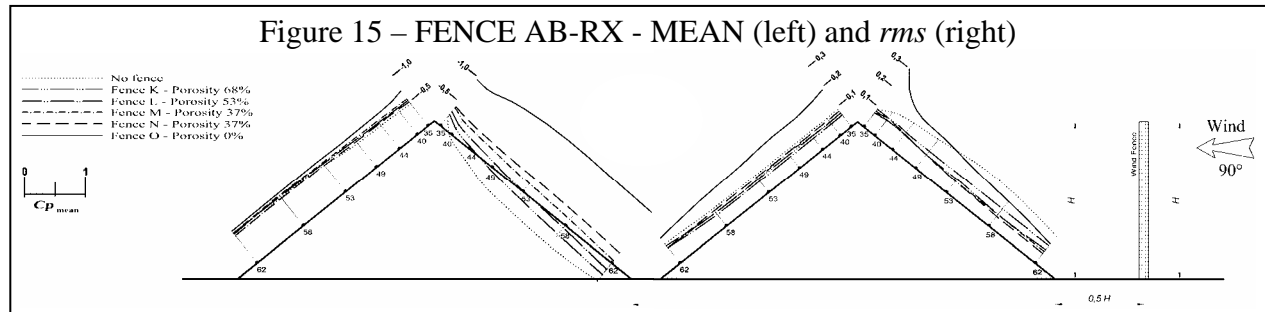
Pressure measurements over the pile surface, with no fence protection, shows clearly the influence of the wind angle of incidence (Figures 15 to 22). The largest pressure coefficients, mean and *rms*, correspond to 30° and 45°. The most affected regions are those next to the pile edges.

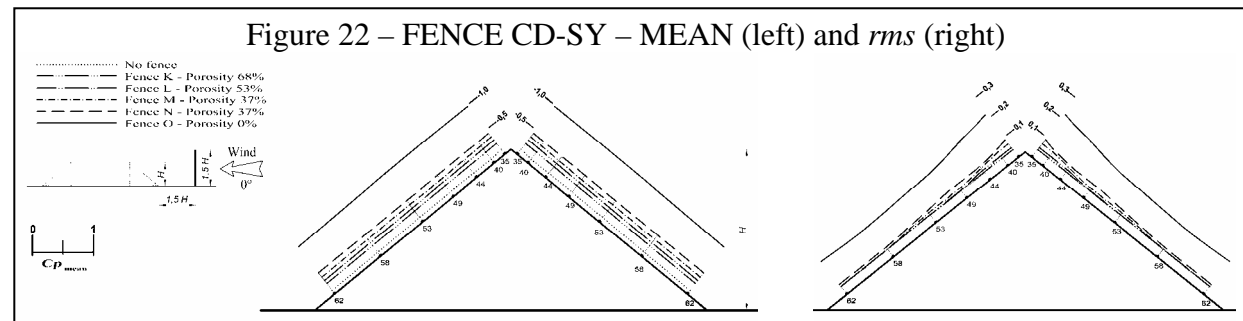
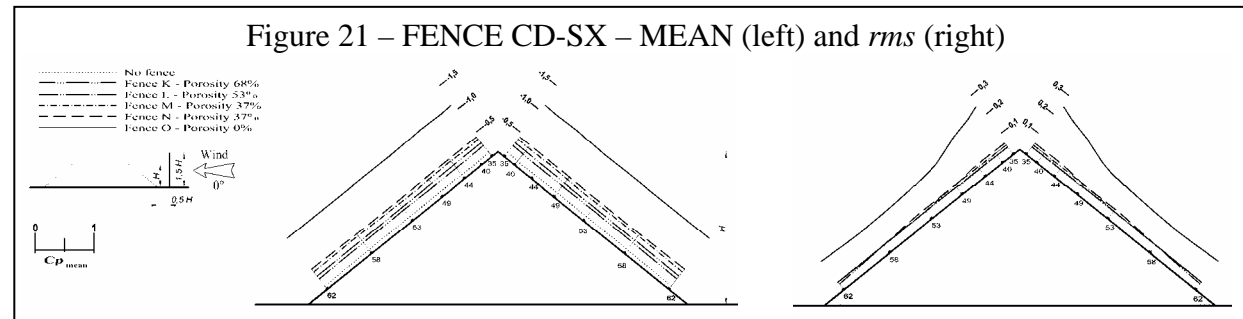
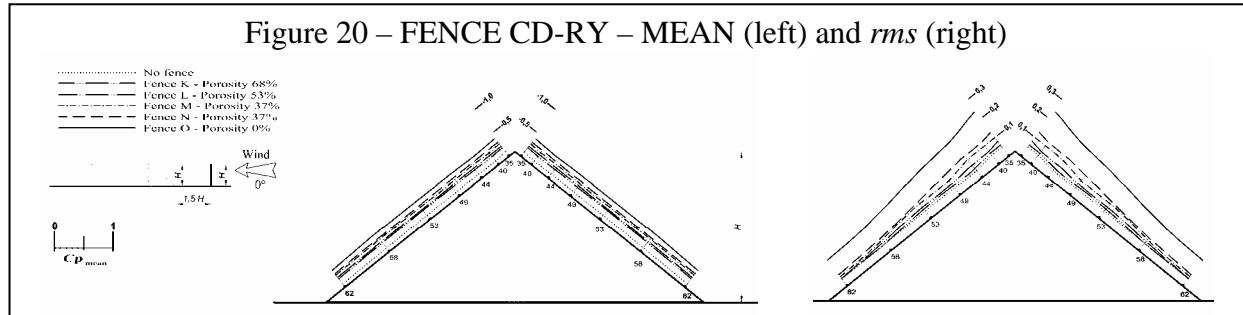
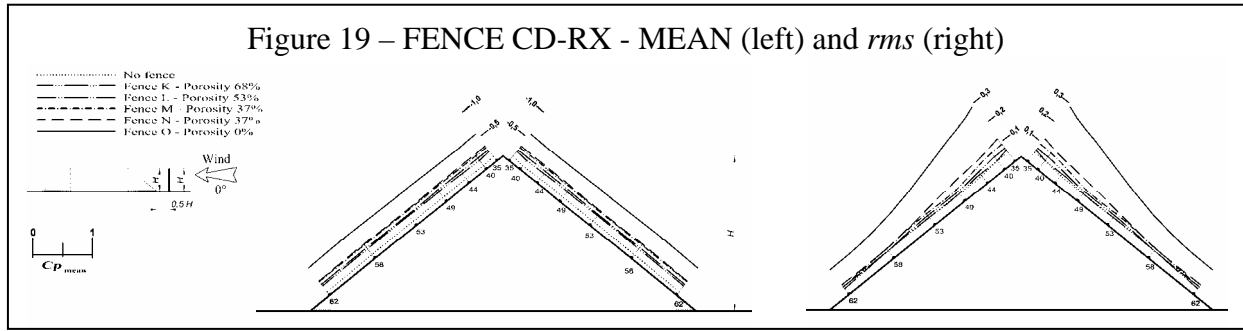
With the presence of the screens, the flow configuration is not substantially altered. However, the pressure values in the cross-section of the piles present significant changes among the several cases.

For configuration AB and same distance, for the taller fence a decrease in $\overline{C_p}$ occurs (more negative means more suction) and an increase of C_p' , which would favor particulate material erosion. In the NO FENCE situation, the mean values have shown the occurrence of positive pressures over a big area in the windward face of the pile, although with higher C_p' values than

those when there is a screen. The case of fence O (plate with 0% porosity) presents the largest absolute values of $\overline{C_p}$ and C_p' , showing that the plate and the pile form a cavity. The distance of the screen also poses an influence in the pressure field, although in a minor order than the porosity or the height of the fence.

For configuration CD, again the height of the fence shows an increase in the absolute value of the pressure coefficients, being fence O the one with the largest values.





CONCLUSIONS

This paper refers to the first phase of the study in wind tunnel of the protection effect propitiated for porous screens to the aeolian transport of coal particles in the CVRD, and it describes the characteristics of the flow around an isolated coal pile with the intention to subsidize the characterization of the local phenomenon of carrying and beginning of the erosion, as well as understanding the influence of protection fences in the flow over the piles.

Mean and fluctuating wind speeds have been measured in selected points over the surface of the model, which are directly related with the emission of particulate material from surface. It is clear that the mean wind speeds are higher next to the top of the pile, and that the presence of the fences cause a reduction of these velocities in the most critical regions. These findings do not imply directly in a reduction of the erosion of the particulate material, since this phenomenon depends on the combined effect of the velocity and pressure fields on the surface of the pile.

Besides the velocity field, mean and fluctuating pressure distributions have been determined for several angles of incidence of the wind, as well as for distinct combinations of porosities, heights and distances of protection screens. From the analysis of the results obtained in the tests, it is possible to observe that the pressure field has a preponderant influence in the beginning of the movement of the particulate material, in relation to the particle tangential drag velocity.

The fence with no porosity (0%) caused an increase in the recirculating zone behind the fence, therefore increasing the negative pressures over the pile surface, being soon disregarded. The fences with porosities ranging from 53% to 68% were most effective in reducing the pressure fluctuations on the windward face of the pile, without increasing significantly the mean pressures over it. These pressures are closely related to the dust emissions from the surface, directly affecting the surrounding environment. However the fences with intermediated porosities (37%) were the most effective in reducing the peak pressures from oblique angles of incidence of the wind.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to the valuable contributions of the members of the *Laboratório de Aerodinâmica das Construções*, namely Prof. Marcelo M. Rocha, Téc. Paulo F. Bueno, Eng. Adrián R. Wittwer, Eng. Elvis A. Carpeggiani, Eng. Gustavo J. Z. Núñez and Eng. Leandro I. Rippel. The gratefulness is extended to the related crew of CVRD.

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